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ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY

1997 PROGRAM PLAN

Electronics and Electrical Engineering Laboratory

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology
Electronics and Electrical Engineering Laboratory

January 1997

NIST

EEEL SEEKS YOUR COMMENTS

The Electronics and Electrical Engineering Laboratory (EEEL) reviews its plans regularly to keep them focused on the most important measurement needs of the U.S. electronics, electrical-equipment, and electric-power industries. Comments on this plan are invited and should be sent to the following address:

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U.S. DEPARTMENT OF COMMERCE
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TECHNOLOGY ADMINISTRATION
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NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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Abstract

This program plan provides a detailed description of the important work that the Electronics and Electrical Engineering Laboratory at the National Institute of Standards and Technology is undertaking to provide measurement capability for U.S. industry. This measurement capability underlies the development, manufacturing, marketing, and after-sales support of new products in industry. The services provided by this program further U.S. economic growth and strengthen U.S. competitiveness in international markets.

The Electronics and Electrical Engineering Laboratory focuses on measurement capability needed especially by the electronics industry, the electrical-equipment industry, and the electric-power industry. This measurements capability also serves government, educational institutions, and the public broadly, either as users of that measurement capability or as customers for the products and services of the supported industries.

Keywords

commercialization of technology; electrical-equipment industry; electric-power industry; electronics industry; international competitiveness; measurement capability; metrology

PREFACE

This document is an integral part of a set of planning documents developed by the Electronics and Electrical Engineering Laboratory (EEEL). These documents cover five principal subjects, listed here in the order in which they are employed in EEEL's planning process: (1) an assessment of industry's measurement needs, (2) the strategic plan for responding; (3) the program plan for realizing the goals of the strategic plan through specific technical efforts (this document); (4) the technical accomplishments resulting from completed work; and (5) the impact of those accomplishments.

This program plan is composed of an overview followed by descriptions of the twelve programs that EEEL addresses. The overview describes the mission, customers, deliverables, resources, structure, and other basic dimensions of the overall EEEL effort in support of U.S. industry. Additional details on these subjects are included in the strategic plan referenced above. Each of the twelve programs described in the program plan, such as "semiconductors" or "lightwaves" (including optoelectronics), is responsive to the measurement needs of a selected field of technology. Most of these fields of technology are associated with specific product categories in industry. The other fields of technology, such as "electromagnetic compatibility" and "national electrical standards", are cross-cutting in nature because they support many product categories. The programs are broken down into projects. The projects may run for a few years or for many years, depending on their complexity. Each project is described in detail. Project descriptions include objectives, background information, resources, the specific tasks addressed, and the milestones required to complete these tasks. These descriptions look both forward and backward in time in order to set the current work in context.

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OVERVIEW

OVERVIEW

EEEL's mission is to promote U.S. economic growth by providing measurement capability of high economic impact focused primarily on the critical needs of the U.S. electronics, electrical-equipment, and electric-power industries, and their customers and suppliers. In fulfilling this mission, EEEL strives to provide leading-edge capability supportive of each of the major steps required to realize competitive products in the marketplace: research and development, manufacturing, marketplace exchange, and after-sales support. EEEL focuses especially on the role of competitiveness in economic growth. Good measurement support is essential for accelerating the commercialization of technology, a primary requirement for improved U.S. competitiveness.

CUSTOMERS

Because of EEEL's primary focus on U.S. industry and its competitiveness, most of EEEL's customers are from industry. When EEEL last completed a comprehensive analysis of its customer base in 1991, about 72 percent of EEEL's customers were from U.S. industry. About 50 percent of the industrial customers were large businesses with over 500 employees, 38 percent were small businesses with 20 to 500 employees, and 12 percent were small businesses with fewer than 20 employees. About 20 percent of the Fortune 500 companies were included in EEEL's customers.[1]

EEEL's customers also include: other government agencies (Federal, state, and local); educational institutions; the research community, whether located in industry, government agencies, educational institutions, or non-profit organizations broadly; and, indirectly, the general public through services to the organizations already named. The measurement capability and other services that EEEL provides to Federal, state, and local agencies help them to fulfill their many responsibilities in areas such as defense, energy, transportation, communications, health, safety, environment, and law enforcement. The characteristics of EEEL's primary industry customers -- the electronics industry, the electrical-equipment industry, and the electric-power industry -- are discussed below.

Electronics Industry

Among U.S. manufacturing industries, the electronics industry is the largest employer with 1.7 million employees, as shown in Table 1. The electronics industry and the chemical industry have the largest values of shipments, each over $300 billion per year.[2]

Table 1: LARGEST U.S. MANUFACTURING INDUSTRIES (1994)

Industry	Shipments ($billions)	Employment (thousands)
Electronics[?(a)]	329	1,670
Chemical[?(b)]	316	842
Automotive[?(c)]	297	934
Petroleum Refining[?(d)]	123	75 (1992)
Aerospace[?(e)]	95	552

The electronics industry produces a broad spectrum of products. This spectrum is outlined in Table 2, using a condensed version of the structure employed by the industry itself through the Electronic Industries Association.[3] In addition, electronic products are built into the products of many other industries, including, for example, virtually all manufacturing equipment, motor vehicles, and aerospace products. Thus, the electronics industry exerts extraordinary influence on the performance of every other U.S. industry.

While the U.S. electronics industry is a strong one, it has been battling for market share in increasingly competitive international markets. There are several indicators of the intensity of this competition. Shipments of this U.S. industry have remained roughly level in real terms in recent years. Employment fell very slowly prior to 1994 but nearly leveled off in that year.[4] The balance of trade overall has been unfavorable and rapidly worsening. Specifically, for the seven broad categories of electronic products shown in Table 2 (exclusive of "Other..."), the balance of trade for 1995 is negative for three and positive for four. Unfortunately, the negative three include three of the four categories with the most trade activity (import plus exports). Within the category with the most trade activity -- electronic components -- both solid-state products and passive components have negative balances. If solid-state products are broken down further into eleven subcategories, nine have negative balances, one has a positive balance and is a small industry segment (solar cells), and the remaining subcategory has a positive balance and is a very large industry segment: chips (integrated circuits before packaging), wafers (silicon before processing into integrated circuits), and parts.[5]

Table 2: ELECTRONIC PRODUCTS

Electronic Components
- electron tubes
- solid-state components
- passive components

Consumer Electronics
- television and other video
- audio
- mobile
- home information
- media

Telecommunications Equipment
- commercial, industrial, military
- broadcast, studio, and related
- telephone and telegraph

Defense Communications
- search and detection
- navigation and guidance

Computers and Peripheral Equipment
- computers
- storage
- input/output
- terminals

Industrial Electronics
- controls
- processing
- industrial process display and control instrumentation
- test and measuring equipment

Electromedical Electronics

Other Related Products and Services

Electrical-Equipment Industry

The U.S. electrical-equipment industry is smaller than the U.S. electronics industry but is still quite large, with shipments of about $50 billion per year.[6] These shipments support other key industries, such as the automotive industry and the electric-power industry, among others.

The products of the electrical-equipment industry are outlined in Table 3, where they are arranged by the basic services that they provide. Included in this outline, among other products, are all of the electrical products used by the electric-power industry. Automobiles, too, rely heavily on electrical equipment, accounting for about 14 percent, by dollar value, of all electrical equipment shipped in the United States.[7]

Like the electronics industry, the electrical-equipment industry is also struggling against strong competitors in many market segments. This competition manifests itself both in small-scale products, such as tiny electric motors, and in large-scale products, such as electric-power generation and transmission equipment.

Electric-Power Industry

The U.S. electric-power industry is composed of the electric utilities, both private and public, and the independent suppliers of electricity. This industry is one of the largest industries in the United States. Electricity sales are $207 billion per year (1995)[8], and the industry employs nearly half a million people (1994).[9] If the electric-power industry were compared with the manufacturing industries in Table 1, its output would fall between the third largest (automotive) and fourth largest (petroleum refining).

At present the electric-power industry is undergoing major changes as it encounters deregulation and domestic competition for the first time. An example of these changes is the emergence of transmission systems as common carriers, shared by multiple and competing suppliers.

Electricity plays an essential role in the manufacture of the vast majority of products. In fact, about 1.3 percent of the value of the products of all manufacturing industries in the United States is attributable to the cost of the electricity used in making them (1993).[10]

Table 3: ELECTRICAL PRODUCTS

Electrical Supply Equipment
- generation
  - generators
- transfer
  - transformers
  - insulation
  - wire
  - wiring devices
- control
  - switchgear
  - relays and controls
- storage
  - storage batteries
  - primary batteries

Electrical Conversion Equipment
- motion
  - motors
- light
  - lighting devices
- heat
  - electrodes and spark elements
- electrolytic action
  - electrolytic elements

Competitiveness

There are many factors that bear on the competitiveness of these industries: social, economic, and technical. Among the technical factors is the need for improved measurement capability. NIST has been a major force in this area and will continue to be. NIST's assistance has strongly demanded by industry in many areas. An example is the additional measurement capability that industry needs to meet conformity requirements, such as electromagnetic compatibility, in order to gain market access.

Simply stated, both the electronics industry and the electrical-equipment industry are outstripping the measurement capability required for international competitiveness. Affected are such important factors such as product performance, price, quality, compatibility, time to market, and implementation of new management strategies, such as concurrent engineering and just-in-time manufacturing.

Similarly the electric-power industry needs new measurement capability to stream-line its generation and delivery methods for electricity to cope with intensifying domestic competition and to realize the aims of deregulation.

DELIVERABLES

EEEL provides three major classes of deliverables. They are listed in Table 4 and are discussed below. EEEL provides measurement capability needed to support the efforts of U.S. industry to improve its competitiveness. EEEL engages in technology development and fundamental research, and EEEL makes the findings available to industry. Each of these categories of deliverables is discussed further below.

Table 4: DELIVERABLES

Measurement Capability
- absolute accuracy
- reproducibility
- materials reference data

Technology Development

Fundamental Research

Measurement Capability

EEEL focuses the largest part of its resources on the development and delivery of measurement capability for two principal reasons:

> Measurement capability has very high impact on U.S. industry because measurement capability supports manufacturers in addressing so many of the challenges that they face in realizing competitive products in the marketplace. A detailed discussion of the dependence of competitiveness on measurement capability is provided in Chapter 1 of *Measurements for Competitiveness in Electronics*.
>
> NIST bears the official imprimatur of the U.S. Government as the lead agency for measurements.

EEEL focuses on developing measurement capability that is beyond the reach of the broad range of individual companies. Thus, EEEL does not develop measurement capability that companies can provide for themselves. Companies seek NIST's help for several reasons:

> The companies need NIST's special technical capability for measurement development.
>
> They need NIST's acknowledged impartiality for diagnosing a measurement problem affecting the industry broadly or for achieving adoption of a solution across the industry.
>
> They themselves cannot develop measurement capability needed by the industry broadly because they cannot individually capture the returns of the cost of development.
>
> Industry's quality standards require that key measurements be traceable to the national measurement reference standards that NIST maintains. This is a requirement of growing importance in export markets.

The reasons for NIST's involvement are reviewed in detail in Chapter 2 of *Measurements for Competitiveness in Electronics*.

Within the area of measurement capability, EEEL places its highest priority on delivering absolute accuracy. This emphasis reflects NIST's unique role as *the* national reference laboratory for measurements. Support for absolute accuracy may require a documented measurement method, a special measurement device, a reference standard to assure the accuracy of the measurement method, and a means of delivery such as a measurement assurance program or a calibration service.

EEEL places its second highest priority on delivering reproducible measurement capability. Reproducible measurement capability provides consistent measurements but does not by itself assure high absolute accuracy.

EEEL also develops reference data on the measured electronic properties of materials. EEEL undertakes this work if NIST's special measurement skills are needed for development, or if NIST's evaluation and imprimatur are needed for wide acceptance. However, when these special conditions do not apply, EEEL prefers to provide industry with measurement capability that industry can use to develop its own data, maximizing EEEL's leverage.

Technology Development

EEEL regularly engages in technology development that directly supports its measurement mission. For example, as part of developing or delivering new measurement capability, EEEL may find it necessary to build a special instrument or an integrated circuit that embodies the new capability. EEEL transfers the technology realized in that instrument or circuit to the private sector, along with the associated measurement capability. Industry may modify the technology for incorporation in commercial products. Also, EEEL sometimes develops technology used for analyzing measured data. Examples include test strategies for complex electronic systems and expert-systems analyses for semiconductor process lines.

EEEL engages in only limited technology development that extends beyond its measurement mission. EEEL limits the fraction of its resources so applied to about 10 percent of the total. For a technology-development project to be undertaken, it must offer unusually high impact. Also, there must be specials reasons for EEEL to be the performer. For example, the project may have arisen from a fortuitous discovery at NIST, or it may require facilities or capabilities available only at NIST.

There are important reasons why EEEL limits the technology development that it undertakes outside of its measurement mission:

> EEEL generally finds that measurement development has the highest impact among the deliverables that it can provide.
>
> EEEL's funding level is far short of that required to meet all of the principal measurement needs of the U.S. electronics, electrical-equipment, and electric-power industries. Therefore, any technology development undertaken outside of the measurement mission reduces the level of measurement support that EEEL can provide to U.S. industry.
>
> Other programs exist to fund technology development, and some have considerable resources. Thus, the additional resources that EEEL could provide would not, in themselves, be significant.

Electronic data exchange is an example of a major technology-development project to which EEEL and other parts of NIST are contributing. This is a national effort. The national goal is the development of methods for codifying information to support multiple industrial needs. An important application is specifying products for manufacturing. EEEL's contributes objectivity to the broader effort focused on developing improvements in the infrastructure used for marketing electronic products. Even though this project is not focused on measurement development, EEEL's role has a measurement character: EEEL will develop methods for testing proposed schemes for data exchange.

Fundamental Research

EEEL defines fundamental research by the nature of the work conducted, not by the reason for undertaking it:[11]

> Fundamental research is the pursuit of the discovery or the understanding of the fundamental phenomena of nature.

EEEL conducts considerable fundamental research as an integral part of many of its measurement-development projects. This is not surprising, since new measurement capability is generally developed at the leading edges of science and technology. Further, EEEL endeavors to maintain a fundamental-research effort in every broad program area. Such research is an important means of nucleating pathbreaking measurement capability. For example, EEEL laid the bases for the present Josephson voltage standard with two successful theoretical inquiries: one on the interactions of series arrays of Josephson junctions, and the other on chaos in Josephson junctions.

Table 5: MEANS OF DELIVERY

Communications	**FY96**
publications	243
software requests	280
talks	309
consultations	2990
visits	480
visitors	440
meetings	
attendees	1730
contributors	91
Joint Activities	
standards organizations	
staff participating	34
memberships	61
professional societies	
memberships	180
cooperative research	140
consortia (incl. forming)	6
guest scientists	96
Paid Services	
custom measurement development	110
standard reference materials	90
calibration service customers	310
training courses	39

Most of the fundamental-research projects that EEEL pursues are focused on topics likely to have outcomes benefitting measurement development for U.S. industry. That is, EEEL conducts *directed fundamental research*. EEEL does not bound the amount of directed fundamental research that it conducts to support its measurement mission. The amount conducted is determined by the needs of the individual projects pursued. For a given project, that amount may be 80 percent of project resources or next to nothing.

EEEL conducts some fundamental research that is not focused on immediate measurement needs. The criteria for identifying suitable projects are similar to those for technology development: unusual opportunity for high impact, and some special reason for EEEL to be the performer. Examples include EEEL's work on determining values for the fundamental physical constants, such as the fine-structure constant and the gyromagnetic ratio of the proton.

MEANS OF DELIVERY

EEEL provides its deliverables by three principal means, as shown in Table 5: communications, joint activities, and paid services. FY 1996 levels of activity are shown in the table. These means of delivery involve regular interactions with industry, government agencies, and educational institutions. The interactions are essential to planning as well as to delivery. Over recent years, the levels of activity associated with the various means of delivery have varied up and down but not with distinct trends. All continue to be important to effective delivery. An examination of the workload on staff members indicates that they are operating at capacity in terms of the number of technology-transfer activities that they can handle.

RESOURCES

EEEL's funding and staff resources for FY 1996, the most recently completed year, are shown in Table 6. EEEL's funding is shown in two major categories: (1) the funds expended *in EEEL*, and (2) the funds expended *outside EEEL*. This second category represents the funds that EEEL transfers to other NIST laboratories for work supportive of its programs. For the funds expended in EEEL, the "NIST Funding" is provided by the Congress directly to NIST. The "Other Agency Funding" is transferred to NIST by other Federal agencies for the development of measurement capability supporting their programs. The "Other Funding" comes from multiple sources, the largest single part of which is derived from reimbursements for the cost of calibrations services provided to EEEL's customers. The funds expended outside EEEL but inside NIST are a combination of funds provided by the Congress directly to NIST and funds provided by other Federal agencies.

At the time this document was written, EEEL's funding levels for FY 1997 had not yet been completely determined; so no funding information for that year has been provided here.

Table 6: FY 1996 RESOURCES

Funds (in EEEL)	$millions	percent
NIST Funding	33.1	73
Other Agency Funding	7.3	16
Other Funding	4.9	11
total	45.3	100
Funds (outside EEEL)	5.9	
Staff	number	percent
paid		
full-time permanent	283	71
other	22	5
total paid	305	76
unpaid		
guest scientists	96	24
total unpaid	96	24
total	401	100

PLANNING

EEEL's planning process includes five principal steps. Each step is reflected in one of the five types of published documents shown in Table 7. Also included there are the typical publication intervals and time horizons.

The needs assessments identify the principal measurement capability for which industry needs NIST's assistance. The most wide-ranging of these assessments is *Measurements for Competitiveness in Electronics*, prepared by EEEL in consultation with U.S. industry and other NIST laboratories and published in 1993.[12] Since then EEEL has expanded upon this analysis by conducting a number of additional assessments that maintain a current picture of the key needs.

Table 7: PUBLISHED PLANNING DOCUMENTS

Document	Publication Interval (years)	Typical Time Horizon (years)
needs assessments	varies	10 forward
strategic plan	3	5 forward
program plan	1	varies
technical accomplishments	1	1 backward
impact studies	varies	varies

The strategic plan describes the overall directions of EEEL's programs in response to industry's needs. The program plan focuses on implementation of the strategic directions in specific program goals and includes both plans and detailed accomplishments. The technical-accomplishments document describes selected accomplishments for the most recently completed year in a form suitable for the general reader. The impact studies translate those accomplishments into economic and other terms and provide perspective helpful in planning new work.

Table 8 provides more information about the two types of planning documents published at varying intervals: the measurement needs assessments and the impact studies. In addition, two key activities that support assessing measurement needs are broken out separately: surveys of industry's measurement needs conducted by EEEL, and reviews of the measurement needs assessments by industry. Table 8 includes the documents published in FY 1993-1996 and, also, the documents contemplated for publication in FY 1997-1998. A full list of all of the documents referenced in Table 8 is contained in the endnote.[13]

As indicated in the key at the bottom of the Table 8, the assessments are marked "a". The review is marked "r" in the table. Reviews may be conducted before or after the publication of the assessment for a given technical field. If conducted afterward, the reviews contribute to the next assessment for the named technical field. The surveys are marked "s" in the table. They may employ a written questionnaire, telephone calls, or visits to gather information from industry's technical and managerial personnel. The impact study is marked "i" in the table. Impact studies are sponsored by EEEL or the NIST Program Office and are conducted with the assistance of economists and industry experts to determine how completed work has affected industry. Finally, for the first time in this program plan, the table reflects measurement needs assessments conducted outside NIST, generally by industry and often with NIST participation. They are included here if they provide specific guidance on measurement needs, similar to the assessments conducted by NIST itself. There is just one of these included this year. It is marked with an [o] in the table and comes from the semiconductor industry. EEEL anticipates an increase in the number of these assessments in coming years, actively encourages their development, and seeks to benefit from the guidance that they provide.

Table 8: MEASUREMENT NEEDS AND IMPACT DOCUMENTS

Fields	'93	'94	'95	'96	'97	'98
semiconductors	a,s	.	.	a,s	[o]	a
magnetics	a	.	.	.	.	.
superconductors	a,i	.	.	.	.	.
low frequency	.	.	.	.	.	.
microwaves	a	.	.	.	.	.
lightwaves	a,r	.	.	.	.	.
computers	.	.	.	.	.	.
video	r,a	.	.	.	.	.
power	.	.	i	.	a	a
Cross-Cutting Fields						
national electrical standards	.	.	.	.	.	.
electromagnetic compatibility	r,a	.	r	.	a,s	.
electronic data exchange	.	.	.	.	.	.

a = assessment of industry's measurement needs
r = review of measurement needs assessment
s = survey of industry's measurement needs
i = impact study
[o] = outside measurement needs assessments

EEEL employs other mechanisms to gather information important for planning. These mechanisms may or may not result in published documents. Among them are individual contacts with industry representatives by all staff members, round-robin measurement intercomparisons, informal customer surveys, and workshops. For example, in consultation with the Telecommunications Industry Association, EEEL periodically updates its understanding of the most important measurement needs affecting the optical-fiber communications industry. EEEL and other laboratories at NIST also participate in the development of industry "roadmaps" that lay out long-range plans for technical progress and improved competitiveness in specific industries. The roadmaps have implications for needed measurement support from NIST but address the specifics needs to varying degrees. Examples of roadmaps important for the electronics industry are these: (1) the roadmap of the semiconductor industry, under the auspices of the Semiconductor Industry Association, which describes specific measurement needs;[14] (2) the roadmap of the optoelectronics industry, under the auspices of the Optoelectronics Industry Development Association (OIDA), which has identified the need for improved measurement capability;[15] (3) and the roadmap for electronic products, under the auspices of the National Electronics Manufacturing Initiative (NEMI) which is examining the needs for improved measurement capability.[16]

ORGANIZATION OF THIS PROGRAM PLAN

The fields of technology that EEEL presently addresses, or plans to address in future years, are shown in Table 9. They provide the basis for the organization of this program plan. Each field of technology is associated with a responsive EEEL program of the same name. This structure has the advantage that it is readily accessible to the three supported industries and thus facilitates communication with EEEL's customers.

Almost all of these fields are seeing rapid advances in technology, in either product technology or manufacturing technology, or both. They are all the subject of current or foreseeable intense competitive pressures. They are increasingly interdependent technologies; success in any one of them is generally tied to success in one or more of the others. Because of this interdependency, it is not possible to create an entirely separable set of fields to describe these technologies and the products made from them. The arrangement in Table 9, however, has been found workable. In this scheme, products are generally associated with the first applicable field on the list, as described in the following several paragraphs.

The three *materials* fields of technology that lead the list (semiconductors, magnetics, and superconductors) represent measurement support provided for those materials, discrete components, and integrated components that are most conveniently classified by the key material from which they are made.

The three *frequency-based* fields of technology (low frequency, microwaves, and lightwaves) that follow represent measurement support for materials, discrete components, integrated components, and equipment that are most conveniently classified by the frequency region employed. Optoelectronics is considered part of the lightwave field, since the use of light is its distinguishing feature.

Table 9: FIELDS SERVED (CURRENT AND FUTURE)

Fields	
semiconductors	
silicon	current
compound semiconductors	current
magnetics	
magnetic information storage	current
magnetic sensing	current
power materials	future
superconductors	
low temperature	current
high temperature	current
low frequency	
radio frequency	current
audio frequency	current
direct current	current
microwaves	
microwave signal processing	current
microwave computing	current
microwave transmission	current
lightwaves	
lasers	current
optical-fiber communications	current
optical-fiber sensors	current
optical information storage	future
optical signal processing	future
optical computing	future
computers	future
video	
vision	future
signal processing	current
transmission	current
information storage	current
displays	current
power	
generation	future
transmission	current
control	current
storage	future
conversion	current
Cross-Cutting Fields	
national electrical standards	current
electromagnetic compatibility	current
electronic data exchange	current

The computer field of technology provides a location for measurement support for equipment and systems important to computers and their peripherals and beyond the measurement support provided for materials and components under semiconductors, magnetics, and video.

The video field of technology focuses on measurement support for integrated components, equipment, and systems that are specific to video and that are beyond the broadly applicable component technologies addressed in earlier entries in the table.

The power field of technology focuses on measurement support for materials, equipment, and systems of principal interest to the electrical-equipment industry and the electric-power industry.

Finally, three cross-cutting fields are shown. The first of these -- national electrical standards -- focuses on developing and maintaining measurement reference standards for the most fundamental dc (direct-current or zero-frequency) quantities, such as dc voltage, dc current, and dc resistance. These standards enable achieving high levels of absolute accuracy in measuring these quantities. They also provide reference values used to support the measurement of related ac (alternating-current or above-zero-frequency) quantities up to very high frequencies. In this way, the national electrical standards support the products of virtually all other fields of technology in the table. These national electrical standards underpin the national measurement system for electrical quantities. These standards also support U.S. participation in the determination of international electrical standards.

The second cross-cutting field -- electromagnetic compatibility -- addresses measurement support required to achieve two related purposes: reduced unwanted emissions of electromagnetic energy from electronic and electrical products; and increased immunity of products to incoming electromagnetic energy. By so doing, this field supports the products associated with virtually every other field in the table.

The third and final cross-cutting field -- electronic data exchange -- focuses on test methods for the evaluation of data systems intended to support the development and manufacture of the products of virtually all other fields of technology in the table. For example, the automated product descriptions that are a part of electronic data exchange support the manufacturing of electronic and electrical products.

EEEL provides some measurement support for all of the fields of technology marked "current" in Table 9. EEEL sees a need to provide support for the several fields marked "future" in the table but lacks the resources to launch significant programs.

EEEL collaborates with other NIST laboratories in providing needed support so that their special skills in related technologies, such as chemistry and mechanical engineering, can be brought into the service of the electronics, electrical-equipment, and electric-power industries. As with any industry, these industries require a broader diversity of support than any one NIST laboratory can provide. As a result EEEL engages in many collaborative activities with other NIST laboratories. The number of such collaborations typically falls between 30 and 60 per year.

The pages that follow describe EEEL's program plan in detail. The program plan is arranged by the programs that correspond one-for-one to the fields of technology shown in Table 9. The same structure is used in EEEL's *1994 Strategic Plan*. Each program is composed of number of projects. The projects are the fundamental building blocks of this program plan. A full list of all of the projects is provided in Table 11 on page 16. Also, within the plan, the page introducing each program indicates any changes in the project structure of that program for 1997.

Descriptions of the projects begin on page 23. The descriptions cover objectives, background information, resources, the specific tasks addressed, the milestones required to complete these tasks, and accomplishments. These descriptions look both forward and backward in time in order to set the current work in context.

ORGANIZATION OF EEEL

EEEL's programs are implemented through the two offices and five divisions that comprise EEEL's organizational structure. A crosswalk from the programs to the organizational units principally conducting them is shown Table 10. The table indicates that a given organizational unit may support the programs associated with more than one field of technology. For example, the Electricity Division supports the programs associated with five fields of technology directly. In addition, a given program may be supported by more than one Division. That relationship is not shown in the table.

Table 10: CROSSWALK BETWEEN EEEL'S PROGRAMS AND ORGANIZATIONS

PROGRAMS: FIELDS OF TECHNOLOGY	ORGANIZATIONS: OFFICES AND DIVISIONS
Semiconductors	Semiconductor Electronics Division Office of Microelectronics Programs
Magnetics	Electromagnetic Technology Division
Superconductors	Electromagnetic Technology Division
Low Frequency	Electricity Division
Microwaves	Electromagnetic Fields Division
Lightwaves	Optoelectronics Division
Video	Electricity Division
Power	Electricity Division
National Electrical Standards	Electricity Division
Electromagnetic Compatibility	Electromagnetic Fields Division
Electronic Data Exchange	Electricity Division
Law Enforcement	Office of Law Enforcement Standards

The five divisions in EEEL manage programs conducted within their own organizational units. The two offices matrix manage programs conducted across the NIST Laboratories.

The first of the two offices is the Office of Microelectronics Programs (OMP). It manages the NIST-wide National Semiconductor Metrology Program (NSMP), which is a focused, matrix-managed effort addressing the semiconductor industry's metrology needs which are identified in the National Technology Roadmap for Semiconductors. This office and the program it manages are NIST funded. NSMP projects are conducted within EEEL and four other NIST Laboratories: the Chemical Science and Technology Laboratory, the Manufacturing Engineering Laboratory, the Materials Science and Engineering Laboratory, and the Physics Laboratory.

The second of the two offices is the Office of Law Enforcement Standards. It manages a NIST-wide program in support of the criminal-justice community and also conducts some of the work of the program. This program is funded entirely by three other Federal agencies: the National Institute of Justice of the U.S. Department of Justice, the National Highway Traffic Safety Administration of the U.S. Department of Transportation, and the Office of Management and Budget of the Executive

Office of the President. The program is conducted within EEEL and three other NIST laboratories: the Building and Fire Research Laboratory, the Information Technology Laboratory, and the Chemical Science and Technology Laboratory.

Table 12 on page 17 associates every project in this program plan with the EEEL organization conducting it, including all five divisions and the two offices.

(Table 11 and Table 12 follow on facing pages to facilitate comparison.)

Table 11: EEEL PROGRAMS AND THEIR PROJECTS

PROGRAMS	PROJECTS
SEMICONDUCTORS	NIST-Wide Semiconductor Programs Metrology for Nanoelectronics Optical Characterization Metrology Scanning-Probe Microscope Metrology Thin-Film Process Metrology Metrology for Simulation and Computer-Aided Design Metrology for Devices and Packages Silicon-on-Insulator Metrology Metrology for Process and Tool Control Interconnect Reliability Metrology Dielectric Reliability Metrology Micro-Electro-Mechanical Systems (MEMS) Plasma Chemistry - Plasma Processing
MAGNETICS	Nanoprobe Imaging for Magnetic Technology Magnetic Instruments and Materials Characterization Magnetic Recording Technology
SUPERCONDUCTORS	Superconductor Interfaces and Electrical Transport High Performance Sensors, Converters, and Mixers Josephson Array Development Nanoscale Cryoelectronics High-T_c Electronics Superconductor Standards and Technology
LOW FREQUENCY	AC-DC Difference Standards and Measurement Techniques Waveform Acquisition Devices and Standards Waveform Synthesis and Impedance Metrology Measurements for Complex Electronic Systems
MICROWAVES	High-Speed Microelectronics Metrology Power Standards and Measurements Impedance, Voltage Standards and Measurements Network Analysis and Measurement Noise Standards and Measurements Antenna Measurement Theory and Application Metrology for Antenna, Radar Cross Section and Space Systems
LIGHTWAVES	Dielectric Materials and Devices Semiconductor Materials and Devices Fiber and Discrete Components Integrated Optics Metrology Optical Fiber Sensors Optical Fiber Metrology High Speed Source and Detector Measurements Laser Radiometry
VIDEO	Video Technology
POWER	Dielectrics Research Metrology for Electric Power Systems
NATIONAL ELECTRICAL STANDARDS	Quantum Resistance and Capacitance Quantum Voltage and Current
ELECTROMAGNETIC COMPATIBILITY	Standard EM Fields and Transfer Probe Standards Emission and Immunity Metrology Electromagnetic Properties of Materials
ELECTRONIC DATA EXCHANGE	Automated Electronics Manufacturing
OFFICE OF LAW ENFORCEMENT STANDARDS	Enabling Technologies for Criminal Justice Practitioners

Table 12: EEEL ORGANIZATIONS AND THEIR PROJECTS

ORGANIZATIONS: OFFICES AND DIVISIONS	PROJECTS
SEMICONDUCTOR ELECTRONICS DIVISION	Metrology for Nanoelectronics Optical Characterization Metrology Scanning-Probe Microscope Metrology Thin-Film Process Metrology Metrology for Simulation and Computer-Aided Design Metrology for Devices and Packages Silicon-on-Insulator Metrology Metrology for Process and Tool Control Interconnect Reliability Metrology Dielectric Reliability Metrology Micro-Electro-Mechanical Systems (MEMS)
OFFICE OF MICROELECTRONICS PROGRAMS	NIST-Wide Semiconductor Programs
ELECTRICITY DIVISION	Plasma Chemistry - Plasma Processing AC-DC Difference Standards and Measurement Techniques Waveform Acquisition Devices and Standards Waveform Synthesis and Impedance Metrology Measurements for Complex Electronic Systems Video Technology Dielectrics Research Metrology for Electric Power Systems Quantum Resistance and Capacitance Quantum Voltage and Current Automated Electronics Manufacturing
ELECTROMAGNETIC FIELDS DIVISION	High Speed Microelectronics Metrology Power Standards and Measurements Impedance, Voltage Standards and Measurements Network Analysis and Measurement Noise Standards and Measurements Antenna Measurement Theory and Application Metrology for Antenna, Radar Cross Section and Space Systems Standard Electromagnetic Fields and Transfer Probe Standards Emission and Immunity Metrology Electromagnetic Properties of Materials
ELECTROMAGNETIC TECHNOLOGY DIVISION	Nanoprobe Imaging for Magnetic Metrology Magnetic Instruments and Materials Characterization Magnetic Recording Metrology Superconductor Interfaces and Electrical Transport High-Performance Sensors, Converters, and Mixers Josephson Array Development Nanoscale Cryoelectronics High-T_c Electronics Superconductor Standards and Technology
OPTOELECTRONICS DIVISION	Dielectric Materials and Devices Semiconductor Materials and Devices Fiber and Discrete Components Integrated Optics Metrology Optical Fiber Sensors Optical Fiber Metrology High Speed Source and Detector Measurements Laser Radiometry
OFFICE OF LAW ENFORCEMENT STANDARDS	Enabling Technologies for Criminal Justice Practitioners

ENDNOTES

1. EEEL's most recent analysis of the composition of its customer base was conducted in 1991 and reflected the preceding five-year period.

2. All shipments figures in the table are *product data* in current dollars. They are also estimates since no firm shipment data for 1994 were available at the time of publication of the referenced documents. Employment figures are industry data. Industry data reflect all products and services sold by establishments in the named industry, whether or not the products are classified in that industry. Product data reflect all products classified in the named industry and sold by all industries. There is some overlap in the products listed in the table. Some electronic products are included in the automotive and aerospace industries. This overlap arises because there is no set of codes in the Standard Industrial Classification (SIC) System, on which all of the figures in the table are based, that is devoted exclusively to the electronics industry. The superscripts in the table refer to the notes that follow: (a) *1996 Electronic Market Data Book*, Electronic Industries Association, pp. 1-2 (1996). The data associated with (b), (c), (d), (e) come from the International Trade Administration of the U.S. Department of Commerce and will be published by the Bureau of the Census in the *Statistical Abstract of the United States 1995* in late 1995. In the past, these data have been published in the *U.S. Industrial Outlook*, but that publication was discontinued with the edition of January, 1994. For (c) the figures shown reflect both the motor-vehicle bodies and supporting parts industries. For (d), the employment data for 1992 are the most recent available and are thus used as an estimator for 1994.

3. *1995 Electronic Market Data Book*, Electronic Industries Association, p. 3 (1995) and product-specific areas throughout the publication.

4. Employment was 1.724 million in 1993 and 1.710 in million 1994. *1996 Electronic Market Data Book*, Electronic Industries Association, p. 1 (1996).

5. *1996 Electronic Market Data Book*, Electronic Industries Association, pp. 3-4 (1996). The balance of trade for 1995 is positive for electron tubes, telecommunications, defense communications, industrial electronics, and electromedical equipment. The balance is negative for passive components, solid-state products, consumer products, and computers and peripherals. Together electron tubes, solid-state products, and passive components comprise the category electronic components which is negative overall.

6. This is a rounded value based on the value of $48 million calculated for 1990. The definition used for the electrical-equipment industry, in terms of SIC codes, was developed at NIST but was influenced by the products of interest to the members of the National Electrical Manufacturers Association. The definition excludes products which employ electrical components for practical applications. For example, excluded are household appliances, transportation equipment, and manufacturing equipment. Most of these excluded products are as much the products of other industries. Further, the excluded products are difficult to bound because electricity is used so widely. Also, excluded from the definition are electronic products. For the most part, they are the products that apply electricity in electrical form rather than as motion, light, heat, or electrolytic action.

7. *Measurements for Competitiveness in Electronics*, First Edition, Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, NIST Report No. NISTIR 4583, from the data for 1990 in Table 13 on p. 38 (April 1993).

8. Preliminary figure for 1995 from the Edison Electric Institute, Washington, DC (October 31, 1996). Total sales of electricity in the U.S. for 1995 were 3.002 million gigawatt-hours.

9. *Statistical Yearbook of the Electric Utility Industry 1994*, Edison Electric Institute, p. 99 (December 1995).

10. *Statistical Yearbook of the Electric Utility Industry 1994*, Edison Electric Institute, p. 96 (December 1995).

11. Some definitions of fundamental research exclude any research undertaken with a view to achieving practical benefits from its successful completion. That is, they add the notion of lack of specific purpose, or for the purpose of advancing knowledge only, to the definition, even if the nature of the work is unaffected by this addition.

12. *Measurements for Competitiveness in Electronics*, First Edition, Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, NIST Report No. NISTIR 4583 (April 1993).

13. All documents referenced in Table 8 are shown below. They cover the period 1993 to 1998.

Semiconductors

1993	a	Chapter 4, "Semiconductors", *Measurements for Competitiveness in Electronics*, First Edition, Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, NISTIR 4583 (April 1993).
1993	s	"$Hg_{1-x}C_xTe$ Characterization Measurements: Current Practice and Future Needs", *Semiconductor Science and Technology*, Vol. 8, pp. 753-776 (1993).
1996	a	*Semiconductor Characterization: Present Status and Future Needs*, W. Murray Bullis, David G. Seiler, and Alain C. Diebold, ed., published by the American Institute of Physics (1996). Reporting on the *International Workshop on Semiconductor Characterization: Present Status and Future Needs*, a workshop on measurement needs conducted on January 30-February 2, 1995 in Gaithersburg, MD, sponsored by the Advanced Research Projects Agency, SEMATECH, the National Institute of Standards and Technology, and other organizations.
	s	*Survey of Optical Characterization Methods for Materials, Processing, and Manufacturing in the Semiconductor Industry*, National Institute of Standards and Technology Special Publication 400-98 (November 1995).
1997	[o]	Anticipated publication of the National Technology Roadmap for Semiconductors, prepared by companies in the U.S. semiconductor industry, under with auspices of the Semiconductor Industry Association, with contributions from NIST.
1998	a	*International Workshop on Semiconductor Characterization: Present Status and Future Needs II*, a workshop on measurement needs to be held on March 23-27, 1998, in Gaithersburg, MD, sponsored by the National Institute of Standards and Technology, SEMATECH, SRC, and the American Vacuum Society's Manufacturing Science and Technology Group. Proceedings might not be published until 1999.

Magnetics

1993	a	Chapter 5, "Magnetics", *Measurements for Competitiveness in Electronics*, First Edition.

Superconductors

1993	a	Chapter 6, "Superconductors", *Measurements for Competitiveness in Electronics*, First Edition.
1993	i	Robert L. Peterson, "An Analysis of the Impact on U.S. Industry of the NIST/Boulder

Microwaves

1993	a	Chapter 7, "Microwaves", *Measurements for Competitiveness in Electronics*, First Edition.

Superconductivity Programs: An Interim Study", Report No. NISTIR 5012 (November 1993).

Lightwaves: Lasers

1993 a Chapter 8, "Lasers", *Measurements for Competitiveness in Electronics*, First Edition.

1993 r Industry review: Chapter 8, "Lasers", *Measurements for Competitiveness in Electronics*, First Edition.

Lightwaves: Optical-Fiber Communications

1993 a Chapter 9, "Optical-Fiber Communications", *Measurements for Competitiveness in Electronics*, First Edition.

1993 r Industry review: Chapter 9, "Optical-Fiber Communications", *Measurements for Competitiveness in Electronics*, First Edition.

Lightwaves: Optical-Fiber Sensors

1993 a Chapter 10, "Optical-Fiber Sensors", *Measurements for Competitiveness in Electronics*, First Edition.

1993 r Industry review: Chapter 10, "Optical-Fiber Sensors", *Measurements for Competitiveness in Electronics*, First Edition.

Video

1993 r Industry review of draft of Chapter 11, "Video", *Measurements for Competitiveness in Electronics*, First Edition.

1993 a Chapter 11, "Video", *Measurements for Competitiveness in Electronics*, First Edition.

Power

1995 i Albert N. Link, *An Evaluation of the Economic Impacts Associated with the NIST Power and Energy Calibration Services*, Electronics and Electrical Engineering Laboratory, National Institute of Standards and Technology, Report No. NISTIR 5565 (January, 1995).

1997 a Measurement needs assessment for the electric-power industry contemplated.

1998 a Measurement needs assessment for the electrical-equipment industry contemplated.

Electromagnetic Compatibility

1993 r Industry review of draft of Chapter 12, "Electromagnetic Compatibility", *Measurements for Competitiveness in Electronics*, First Edition.

1993 a Chapter 12, "Electromagnetic Compatibility", *Measurements for Competitiveness in Electronics*, First Edition.

1995 r Industry review of *EMI/EMC Metrology Challenges for Industry* - *A Workshop on Measurements, Standards, Calibrations, and Accreditation*, Boulder, Colorado (January 25-26, 1995).

1997 a Contemplated publication of the findings of the *EMI/EMC Metrology Challenges for Industry* - *A Workshop on Measurements, Standards, Calibrations, and Accreditation*, Boulder, Colorado (January 25-26, 1995).

1997 s Contemplated publication of Ramon C. Baird and Motohisa Kanda, *Electromagnetic Compatibility: Results of a Limited Survey*.

14. Next publication anticipated in 1997.

15. Optoelectronic Technology Roadmap, Optoelectronics Industry Development Association, p. 6 (October, 1996). EEEL is participating in the workshops that support the OIDA effort. Two of the most recent in which EEEL participated are the OIDA Technology Workshop on Optoelectronic Sensors in Albuquerque, New Mexico (March 7-8, 1995) and the OIDA Manufacturing Infrastructure Workshop in Rockville, Maryland (June 18-19, 1996).

16. NEMI expects to publish its next roadmap in early 1997.